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Spacecraft Telecommunication System Design**

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Summary

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Telecommunication systems for instrumenting interplanetary spacecraft are required to perform the functions of tracking, telemetry, and command. The design of these systems involves an iterative process of balancing many ~~iterrelated~~ interrelated factors beyond the communication parameters that directly determine signal-to-noise ratios. In this process, the designer must carefully consider the effects on the total spacecraft design and ground instrumentation of such factors as coverage requirements, spacecraft power requirements, spacecraft antenna options, information rates, spacecraft data handling, temperature control, operations, and control of redundant elements.

Consideration of these factors is reviewed with discussions on the establishment of the telecommunication requirements, design trade-offs, design restrictions, and parameter management. Particular emphasis is placed on unmanned spacecraft which must operate with an established, (and consequently) relatively inflexible, but optimised ground instrumentation facility.

Effects of the design considerations are illustrated with a description of an integrated telecommunication system design as used on the Mariner II spacecraft.

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(NASA

1. Introduction

The design of telecommunication systems for instrumenting interplanetary spacecraft is an iterative process of balancing many interrelated factors. A large proportion of these factors are in addition to the transmitter power, antenna gains, bandwidths, and receiving noise temperatures that directly determine telecommunication signal-to-noise ratios. The designer must carefully consider the effects on the total spacecraft design and ground instrumentation of such factors as coverage requirements, spacecraft power requirements, spacecraft antenna options, information rates, spacecraft data handling, temperature control, operational factors, and control of ~~testing and calibration~~ redundant elements.

Telecommunication systems for interplanetary spacecraft are required to perform the functions of tracking, telemetry, and command and in general consist of three subsystems, as shown in Bild (Fig.) 1. The establishment of the requirements for these functions is the first step in the design process. In an ideal case, the designer would like to be given a firm set of requirements that his design must meet and proceed in an orderly fashion ~~fasticon~~ to a final design. In most programs, however, it is necessary to start with an estimate of what the final requirements might be, design a system to fulfill those requirements, determine the cost of the system in terms of spacecraft weight, complexity, required developments, manpower, and funds. Where the requirements can not be met with a design that is feasible in terms of the available technology, manpower, and funds, it is necessary to successively adjust the requirements and the design until a satisfactory balance between requirements and resources is achieved.

The design problem in early spacecraft telecommunication system designs such as Microlock, [redacted] and Trac(e) (References 1, 2, and 3 ~~3,~~ and ~~4~~) were characterised by the availability of very little design flexibility in the spacecraft end and considerable flexibility at the ground stations. In the spacecraft the options were limited by extreme power and weight restrictions relative to the communication requirements while those on the ground were limited only by the designer's inginuity and his monetary resources. Since there were no established ground receiving facilities, the ground station designers had a relatively wide choice of antenna types and receiving techniques at their option.

As the sizes of spacecraft have ~~has~~ increased, so have ~~has~~ the options that are available to the designer. ~~However, as a result of~~ The number~~s~~ of sets of equipments required, the need for well trained personnel, and the need for uniform established procedures in large ground networks, ~~it~~ have made ~~become~~ economically infeasible ~~to make~~ frequent, major design changes. ~~Therefore~~, ~~with~~ The establishment of complex, expensive ground facilities on the ~~such as the Deep Space Instrumentation Facility (DSIF), Reference 5,~~ other hand has reduced the ground station options that are available ~~to the designer~~.

This report reviews consideration of the major factors that influence spacecraft telecommunication system design with discussions on the establishment of the telecommunication requirements, design trade-offs, design restrictions, and parameter management. Particular emphasis is placed on systems for unmanned spacecraft which must operate with an established, (and consequently) relatively inflexible, ground station network such as the Deep Space Instrumentation Facility (Reference) that has already been optimised as to (1) site placement for coverage, low noise environment, and economics (2) state of the art antenna, receiver and instrumentation design, and (3) operating frequency.

Effects of the design considerations are illustrated with a description of an integrated telecommunication system design as used on the Mariner II spacecraft.

Footnote (1) ~~A thorough desciption of the Deep Space Instrumentation Facility may be found in a companion paper, Reference 5, and in References 6 and 7.~~

2. Telecommunication Requirements

The design of a spacecraft telecommunication system ~~that must utilize an established ground instrumentation facility~~ starts with an estimate of the requirements for the tracking, telemetry and command functions. These requirements are estimated on the basis of the mission that the spacecraft must perform and the flight sequence that the spacecraft will follow.

A typical flight sequence for a Mariner type spacecraft (Reference 6) consists of the following events and phases: Prelaunch testing, launch, one or more powered flight phases, injection into transfere orbit, pre-maneuver cruise, one or two midcourse maneuvers, post maneuver cruise, planetary encounter, and post encounter cruise. Each of these phases place different requirements on the telecommunication system. For example, during the ~~premidcourse~~ pre-maneuver cruise phase, tracking data and telemetered performance[1] data may be the most important while telemetered experimental data may be most important at planetary encounter and immediately following.[2]

2.1 Tracking

The tracking requirements are derived from two factors (1) how closely the spacecraft must be maneuvered relative to the celestial objective and (2) how accurately the final trajectory must be known for the interpretation of telemetered data and evaluation of the maneuvers.

Footnotes

1. Performance data as used here refers to data that is used to evaluate how well the spacecraft and instruments are ~~is~~ operating while experimental data refers to the data that indicates the outcome of specific experiments.

2. This is a general observation in the study of several Mariner missions. The actual relative importance of the data as a function of time varies with the particular mission objectives.

The guidance capability of currently available launch vehicles is not accurate enough to perform planetary missions of the Mariner type without further vernier correction by midcourse maneuvers. In order to determine the required maneuvers which are performed approximately one to ten days after the injection into a heliocentric orbit, it is necessary to measure the angular postion, radial velocity, and (sometimes) the range of the spacecraft as functions of time. The accuracy to which the spacecraft orbit can be determined is a function of many parameters. However, it is a particularly strong function of the number of tracking data samples, and how soon after injection these are taken.

As shown in Bild (Fig.) 2 the earliest tracking data is the most valuable in reducing the uncertainty in the orbit parameters as expressed in terms of the miss distance at the target (Reference ~~8~~ 5). The effect on the telecommunication system design of a requirement for early data, is to require communication coverage when (1) the attitude of the spacecraft relative to the tracking stations is unstabilized, (2) the attitude is changing rapidly, and (3) the radial velocity relative to the tracking stations is varying rapidly ~~(0 to km/sec 2)~~ over a wide range (±10 km/sec).

Since the angular velocity decreases rapidly to the sideral rate (to within 1 percent of sidereal within 6.5 hours), ~~radial Reference 9~~ radial velocity or Doppler frequency shift data is the most useful over a major portion of a planetary flight provided it is of sufficient accuracy.

The stability of present spacecraft borne crystal oscillators limits one-way Doppler frequency measurements to an accuracy of about 30 m/sec while two-way doppler frequency measurements can be made to about ~~1.0~~ 0.3 cm/sec (References ~~10~~ 4 and 6). The 30m/sec. figure is not good enough for Mariner type missions while the ~~1.0~~ 0.3 cm/sec. figure is sufficient. Thus a requirement for two-way Doppler tracking places a requirement for the spacecraft to simultaneously receive and transmit CW radio signals. In addition the signals must be phase coherent to within an acceptably small error, usually less than 0.5 radians rms.

2.2 Telemetry

Telemetry requirements on interplanetary spacecraft include the conditioning, multiplexing, storing, and encoding of signals not only from the instruments that may constitute the primary mission experiments, but also those representing a large number of spacecraft performance measurements. The establishment of the total number of signals that must be accommodated and the detail requirements for each is one of the more difficult design problems and requires much iteration before a firm design can be attained.

There are two main categories into which the telemetered measurements can be divided, although some special cases can represent both categories. - experimental and performance. Experimental measurements include those in which the objective is to measure the external environment of the spacecraft, the properties of a celestial body, or the outcome of an engineering experiment. Performance measurements include those in which the objective is to measure how well the spacecraft and its instruments perform as a machine such as voltages, currents, impedances, temperatures, pressures, and mechanical motion.

The performance measurements can be further classified as to whether they are for operational, engineering evaluation, or failure diagnosis purposes. While some measurements may fall in only one of these categories, many can be classified in all three. The importance of these classifications is that they partially establish the relative priority of the performance measurements. For example, an operational measurement that is required for the in-flight control of the spacecraft (in most cases) would be assigned a higher priority ~~be more important~~ than one that establishes only how well a spacecraft element worked.

The weighting that is given to the experimental and performance measurements determines the basic organization of the on-board data handling plan and is determined primarily by the mission objectives. ~~It is, however, a rather controversial subject and as such is not easy to define during the early design phases.~~

Further classifications of the measurement signals that are important in the establishment of the data handling plan are the form of the signals, the relative level of the signals, ~~the relative level of the signals,~~ the measurement requirements, the subsystem source, and the time at which a signal source is active. The ordering of the signals under each of these classifications as shown in Tables ~~4~~ I, II, III & IV is helpful in the detailed mechanization of the data handling system on the spacecraft.

2.3 Command

The problem of establishing the command requirements is similar to that of establishing the telemetry requirements except that there are only two types of commands to be considered and these two types usually can be kept independent of each other. Finalization of the total number of commands and their functions for a particular spacecraft can be achieved only after the control requirements of all spacecraft subsystems ~~has~~ have been established.

The two types of commands to be considered are ~~(1)~~ those that result in an immediate event upon receipt such as a switch closure or motor ignition and ~~(2)~~ those that control the magnitude and polarity of a spacecraft function. The former are called discrete commands while the latter are called quantitative commands. As may be expected the number of commands that will be required will depend on the size and complexity of the spacecraft. However, it will also be a strong function of the operational control philosophy of the spacecraft. A spacecraft can be designed to operate almost entirely under the control of an ~~interal~~ internal sequencing, computing, and logical control system; entirely by radio command; or by combinations of varying degree. The Mariner and Surveyor spacecrafts are examples of different philosophies where the Mariner uses a combination of internal and external control while the Surveyor uses external control almost exclusively. The effect can be seen in the number of discrete commands per hundred pounds of spacecraft, ~~22~~ 2.5 for Mariner and ~~17~~ 12 for Surveyor.

Table ~~II~~ V illustrates a typical Mariner command list.

Where a combination of internal and external control is used, significant improvements in spacecraft reliability can be achieved by using redundance of control where the same functions are controlled by both internal and external commands. Power and weight restrictions usually preclude using this technique for all controlled functions. Therefore, careful failure mode analyses are essential to achieving an efficient use of the gross internal and external command capabilities.

3.0 Design Trade-offs

As with any engineering task, the design of spacecraft telecommunication systems offers a number of trade-offs that the designer can use to optimise various aspects of the design. It is important that he be aware of and analyse these trade-offs. A particularly interesting example is the trade between transmitter power and antenna size for an attitude stabilized spacecraft, such as Mariner, that uses a high gain directive antenna.

The total spacecraft weight that is attributable to the radio transmission function is composed of the weights of (1) the transmitter, (2) the transmitter power supply, (3) the antenna, (4) the antenna support structure, (5) the antenna pointing servo, (6) the antenna servo power supply (7) part of the basic spacecraft attitude control system and (8) the solar or battery energy source. Under the condition of a fixed transmitter power-antenna gain product, items (1), (2), and (8) decrease while items (3) through (7) increase but at a slower rate with increasing antenna gain. ~~as shown in Bild (Fig.) 3~~. Thus for a given power-gain product and hence information rate, there is a particular antenna gain and transmitter power level at which the spacecraft weight is minimized (Reference ~~10~~ 7). A typical curve that illustrates this trade-off is shown in Bild (Fig) 3. It should be noted that the shape of the curves and the location of the minima will depend on the design of the elements.

This trade-off can be used over a relatively wide range of power-gain products (approximately 50 dbm to 75 dbm); however, there are a number of restrictions that also must be ~~also be~~ considered. At high power gain products, the size of the antenna usually becomes restricted by practical pointing accuracy capabilities ~~requirements~~ and the mounting space that is available for the antenna.

4.0 Design Constraints

In many areas of spacecraft telecommunication system design, the lattitude of choice is restricted by ~~many~~ subtle considerations in addition to those of power and weight. Often the designer will find that the considerations of spacecraft size, environment, inflexible schedules, and economics are most significant.

4.1 Spacecraft Size

The size and shape of spacecraft are restrictive in a complicated and interrelated manner as there is considerable competition among spacecraft subsystems for view angles, equipment space, power, and weight. Solar panels, antennas, attitude reference sensors, motor exhausts, scientific instruments, booster attachments, and capsule attachments all require unobstructed angular areas about the spacecraft. In particular, craft ~~xkk~~ that are powered by solar energy such as the Rangers and Mariners require relatively large areas that face the sun with consequently less spherical area being available for antenna radiation. Bild (Fig.) 4 shows the solar panels on a Mariner spacecraft.

Careful integration of the antennas with the spacecraft structure is therefore essential to achieving good antenna coverage and best utilization of the fields of view. Toward these goals the antenna design must be based upon the requirements listed in Table IV.

Mariner type spacecraft require reception and transmission capability via both low gain, quasi-omnidirectional antennas and high gain, directional antennas. Providing the low gain capability is the more difficult design problem since the sizes of current spacecraft are large compared to the operating wavelength and it is necessary to limit the amount of RF energy that is directed toward the spacecraft. Energy that is intercepted by the spacecraft is reradicated, generally in a manner that interferes with and distorts the primary radiation pattern. Further, strong RF currents in the spacecraft structure can interfere with other spacecraft radio equipment and sensitive instruments.

The low gain Mariner antenna shown in Bild (Fig.) 4 is a reasonably good solution to a low gain antenna problem. The antenna consists of a discone antenna mounted on a tower with its null axis coincident with the spacecraft roll axis. A ground plane mounted below the antenna provides additional shielding from the spacecraft.

4.2 Environment

The technology for building spacecraft borne electronic equipment that will function over the normally encountered spacecraft temperature ranges and mechanical vibration environments is well advanced. However, the very important scientific quest for evidence of life on other celestral bodies places severe sterilization requirements on any spacecraft that is expected to land on Mars for example. Of several sterilization methods that are being developed, the most favored consists of soaking all of the spacecraft for a period of 24 hours or more at a temperature of 135°C.

The design of electronic equipment that will not only survive this treatment but also maintain calibration and performance tolerances is a difficult engineering task that will require undesirable compromises in performance and reliability. For example to meet such a sterilization requirement, silicon rather than germanium semiconductor devices were used in the Mariner transponders at the cost of lower circuit efficiency and an increased receiver noise figure.

4.3 Schedules

The launching schedules for planetary intercept missions are uniquely inflexible. In order to achieve usefully sized spacecraft with the boost vehicle energies that are currently available, the launching periods are restricted to approximately a one month duration when the planet of interest is in a favorable position with respect to spacecraft weight, communication range at encounter, geometry at encounter, and guidance requirements.

Bild (Fig.) 5 illustrates the periodic availability of several of the nearby planets. It can be seen that a one month delay in spacecraft preparation causes launching delays of 18 and 22 months for flights to Venus and Mars respectively.

When working to such inflexible schedules and ones that are short as well, the telecommunication system designer must choose his design carefully, being sure that:

1. The system is for the most part is based on proven techniques and requires a minimum of new developments, Bild (Fig.) 6 .

2. The system mechanizations are well understood, implying that the mechanizations can be analysed to the accuracy necessary to give a reasonable confidence level in meeting the performance requirements, Bild (Fig.) 7.

3. New developments will have sufficient support in manpower and money, and that there is a well established back up technique that can be relied upon should the new development run into difficulty, Bild (Fig.) 8.

In general, because of both the scheduling and economic restrictions, it is usually necessary for the designer to choose a less sophisticated, less efficient design (from the communication point of view) to achieve the mission objectives with a reasonable risk. An example of this approach is apparent in the Mariner receiver where a ~~noiser~~ crystal mixer input circuit was chosen with a consequently higher noise figure rather than a parametric or tunnel diode type, Reference 8.

4.4 Economics

The importance of the economic considerations in all aspects of telecommunication system design are almost obvious. However, one aspect is particularly important when a space flight mission requires the services of a large network of ground stations and several spacecraft must be prepared simultaneously. Under these conditions the cost of the special ground support equipment that is needed to test and calibrate the telecommunication equipment before flight and to handle the particular spacecraft signals at the ground receiving stations exceeds the cost of the actual spacecraft equipment. A comparison between the flight equipment costs (including development and spares) for a Mariner telemetry subsystem and the associated delete ground support equipment ~~is shown in Table VII~~ indicates that the ground support equipment costs 20 percent more than the flight equipment.

The important point is that the designer must carefully weigh the costs and advantages of adding improvements or modifications to each telecommunication system design when such changes obsolete quantities of expensive equipment.

5.0 An Integrated System for Mariner II

The telecommunication system for the Mariner II spacecraft illustrates an integrated design in which single RF links between earth and spacecraft and vice-versa are used for the functions of tracking, telemetry, and command. As may be seen in the block diagram, Bild (Fig.) 9, the telemetry subsystem includes signal conditioning and multiplexing circuits, an analog-to-digital converter, a controller, and a phase-shift keying modulator.

The radio subsystem receives an 890 mc. signal via a low gain array and coherently detects the signal in an automatic phase control transponder that also serves as the transmitter exciter. The transmitted signal, at a frequency of $\frac{96}{89}$ th of the received frequency is phase modulated by the telemetry subcarrier and amplified to a level of 3.0 watts. Transmission via either a low gain antenna or a high gain is selectable by command.

Command subcarriers which phase modulate the earth to spacecraft RF carrier are demodulated in the transponder receiver, detected and decoded in the command decoder, and distributed to the appropriate spacecraft subsystems.

The system was required to be compatible with the Deep Space Instrumentation Facility in order to permit angular position and two-way Doppler-frequency-shift (radial velocity) tracking to the accuracies and resolutions shown in Table VIII. The actual Doppler tracking accuracy that was achieved far exceed the requirements and was within 0.003 m/sec rms. (Reference ~~9~~ 6).

The telemetry data requirements, Table IX, include data from both performance evaluation measurements and scientific experiments. From the performance evaluation measurements, 48 were sampled analog signals, one a digital signal, and 4 were cummulative event signals. From the scientific experiments, 12 were sampled analog signals while 7 were digital signals. During the cruise phases the single channel was time shared by alternating blocks of performance and scientific data. During the maneuver phases it was utilized exclusively for performance data while during the planet encounter phase, it was utilized exclusively for scientific data.

The telemetry transmission requirements, Figure X, were met by a two subcarrier modulation technique. One subcarrier was bi-phase modulated by the binary data signal, the other was bi-phase modulated by a pseudorandom binary sync code that conveyed both bit and word sync. By means of this technique synchronous demodulation and matched filter detection could be used at the ground stations with resulting high communication efficiency.

The command requirements as listed in Table XI, were met using a modulation demodulation technique similar to that used for the telemetry transmission.

In conjunction with the DSIF, this system demonstrated the capability to perform accurate, reliable communication to and from spacecraft to a distance of at least 85 million km. Approximately 90 million bits of information were received with an accuracy of at least one per cent for digital data and 3 per cent for analog data using a transmitter power of only 3 watts (Reference ~~9~~ 6).

6.0 Parameter Management

6.1 Need for Control

In current spaceflight programs, tight control of the telecommunication system parameters is a necessary ingrediant for successful system management. This need arises from ~~two~~ factors, such as the fact that ~~(1) the overall system performance depends on how well a large number of individuals carry out their respective responsibilities and (2)~~ the overall spacecraft design can not afford large, arbitrary safety factors in signal-to-noise ratio.

~~In the early spaceflight projects such as the first Explorer satellite series and the Pioneer III and IV lunar probes,~~ (References 1, 2 and 3) ~~the signal-to-noise ratio performance of the telecommunication system depended on the performance~~ of ~~not more than ten or twenty individuals given a successfully launched spacecraft. Since all of these individuals worked within the same organization, the control of their performance and the resulting system design parameters was a relatively straight forward management task that could be handled quite informally.~~

~~With the advent of larger more complicated spacecraft that operated with world wide tracking networks where several separate organizations are responsible for the establishment and maintenance of the various system parameters, it soon became apparent that a more formal control of the system parameters was necessary. At times there were as many different estimates of system performance as there were estimators.~~

A ~~principle part of the difficulty lay in the~~ was differences ~~definitions~~ of ~~system thresholds and the definitions of adequate performance margins.~~

Delete

~~In the designs for point-to-point radio communication circuits and circuits for other similar communication services~~ it is ~~it's not uncommon to find arbitrary performance margins of 20 db or more. However, the extreme power and weight restrictions within which spacecraft telecommunication systems must be designed, performance margins of not more than 6 to 10 db can be tolerated. Under such a restriction, the practice of allowing each participating engineer to assign his own arbitrary pads is a particularly deadly practice and strict control of the parameters is necessary.~~

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6.2 Design Control Technique

In order to handle these problems and maintain a reliable estimate of the overall system signal-to-noise ratio performance a simple accounting technique can be used.

As shown in Table XII ~~Bild (Fig.) 10~~ all of the parameters that contribute to the system performance are listed in the approximate order that one would find in tracing a signal through the system. Each parameter is listed in terms of a nominal or design value and a tolerance band along with the responsible engineer or agency.

In assembling such a tabulation the following set of rules are applied:

(1) The nominal value and tolerance for each parameter is attested to in writing by the cognizant engineer or agency.

(2) Any arbitrary padding or use of safety factors within the nominal values are strictly forbidden.

(3) If any arbitrary ignorance factors are necessary such as an allowance for an unknown propagation medium they are placed in the tolerances and appropriately labeled.

(4) The tolerance band must account for variations due to manufacturing, measurement, adjustment, component instability, and environment during the spaceflight.

(5) The threshold signal level is the signal level that results in a threshold signal-to-noise ratio in the effective noise bandwidth of the detector.

(6) The threshold signal-to-noise ratio is that which results in the minimum acceptable ~~as useful~~ output signal quality. It will depend not only on the type of detector being used but also on the type of signal that is applied to the detector and how the output signal is to be used.

Using this tabulation, the ratio of the nominal received signal level to the threshold signal level for each telecommunication function is computed (in db) and defined as the nominal performance margin. The linear sum of the parameter tolerances is used as the tolerance on this margin. For a ~~particular~~ system design to be considered adequate experience has shown that it is adequate but not excessive design practice ~~reasonable~~ to require that the nominal performance margin be positive (in db) and equal to or greater than the magnitude of the adverse tolerance on the margin.

Such a Telecommunication Design Control Table as shown here indicates the performance for only one ground station, spacecraft mode, and range point. By computing the performance as a function of time - taking into account the spacecraft trajectory, attitude, and modes of operation - and plotting it as shown in Bild (Fig.) 10 a useful picture of the overall system performance is obtained. The periods of acceptable, marginal, and unacceptable performance are readily seen for an entire mission.

The advantages of the design control table technique are that first it formalizes the accounting of system performance in a uniform manner that facilitate the comparison of competing systems. Second, it minimizes if not eliminates hidden pads or safety factors and the resulting over design. Third, it standardizes a criterian for an adequate system design. Fourth, it readily indicates the least controlled parameters of the system (those with the largest tolerances) and hence the most profitable areas where improvement can be achieved if needed.

The technique results in what is sometimes referred to as a "Worst Case Design" and one may properly question the degree of conservatism that results from the criterian for an adequate design. In particular does not allow for an understood and controlled variation of design risk as the use of the statistically expected value~~s~~ and variance~~s~~ of the performance margin ~~parameters~~ might allow. If the probability distributions were known for each parameter, it would be a simple matter to compute the mean and variance of the overall system performance. However, the required distributions are functions of many factors including (1) the individual subsystem engineer's ability to meet his performance objectives (2) the reliability of the communication equipment (3) the day-to-day skill and reliability of the system operators (4) the space environment, and (5) the weather at each ground station. These are not known. Thus, few design engineers are able to specify the relationship between the nominal design value of a parameter and its mean or the relationship between the tolerances and the variance of a parameter.

Therefore, a reliable, valid statement of the probability of achieving a given performance margin for spacecraft telecommunication systems is not feasible with our present knowledge. On the other hand, the worst case design technique ~~was~~ has been used on the highly successful Ranger and Mariner II telecommunication systems. ~~For example, the Mariner II performance margin for the command function at encounter (a range of 57.6×10^6 km) was 0.3 db and~~ For example the Mariner II spacecraft was successfully commanded at encounter (a range of 57.6×10^6 km) when the performance margin was only 0.3 db.

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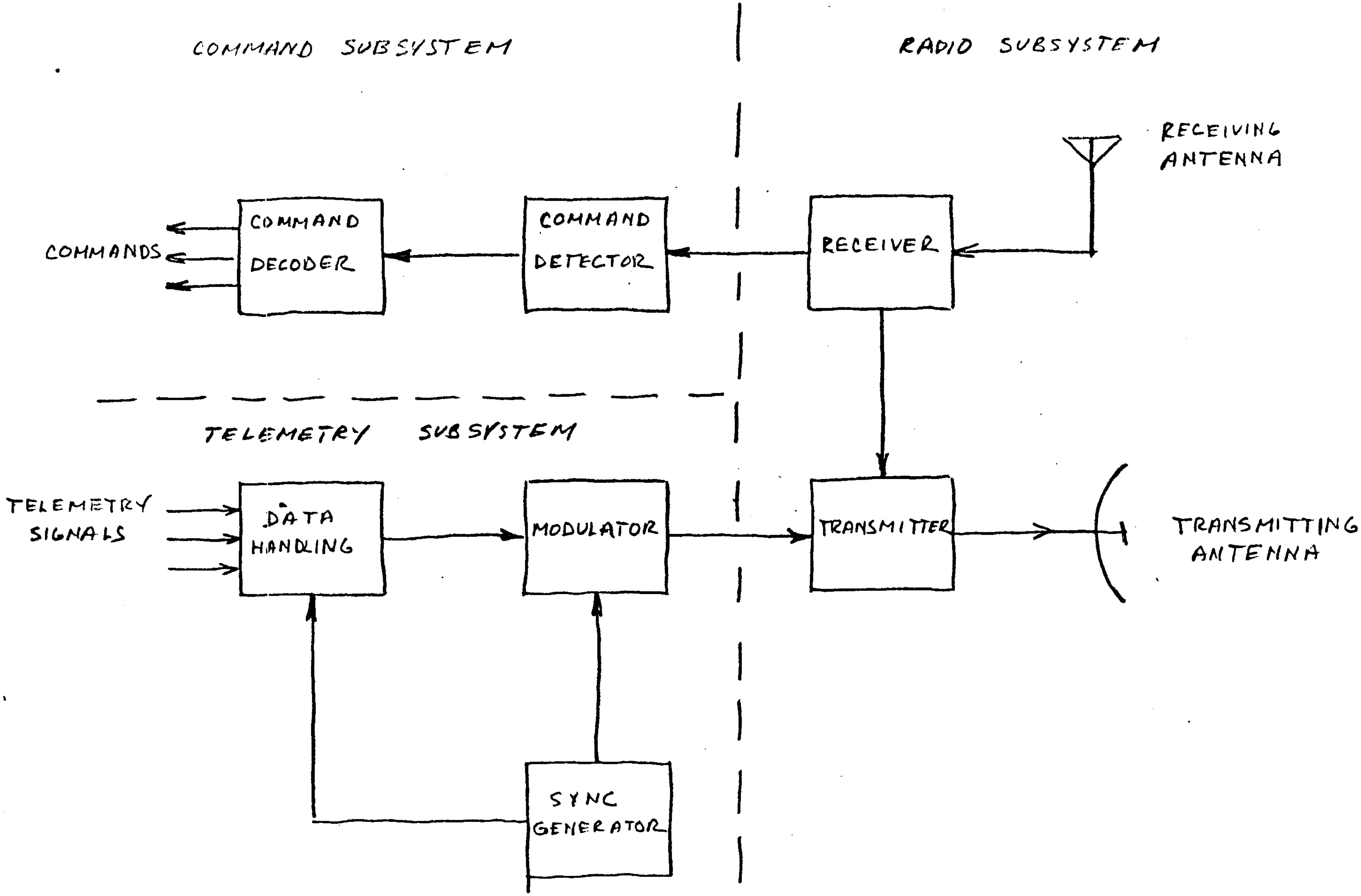

BILD (FIG) 1

TYPICAL SPACECRAFT TELECOMMUNICATION SYSTEM

RAM
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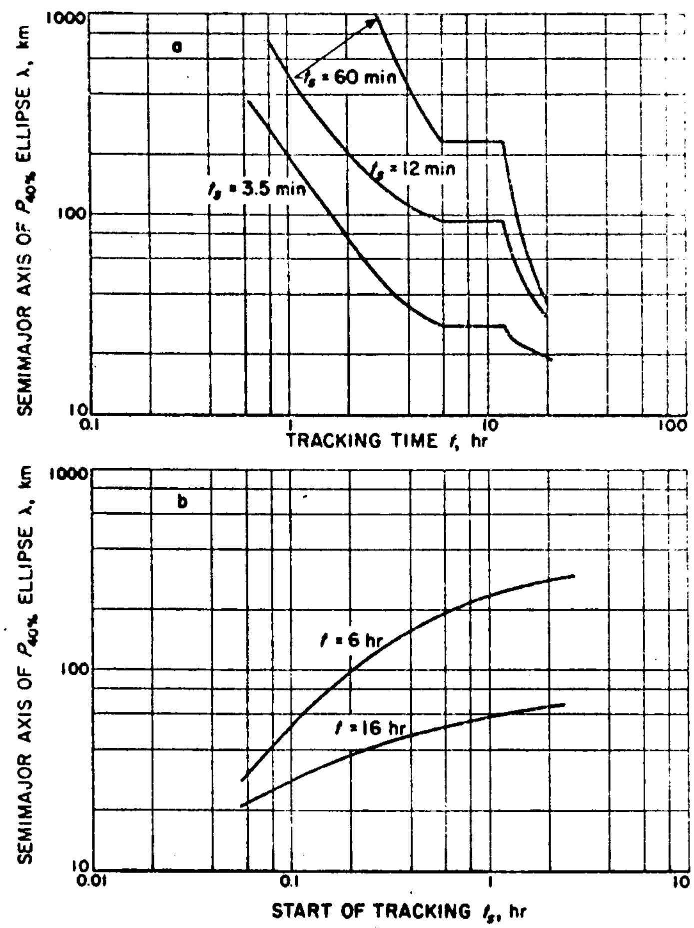


Bild (Fig) 2

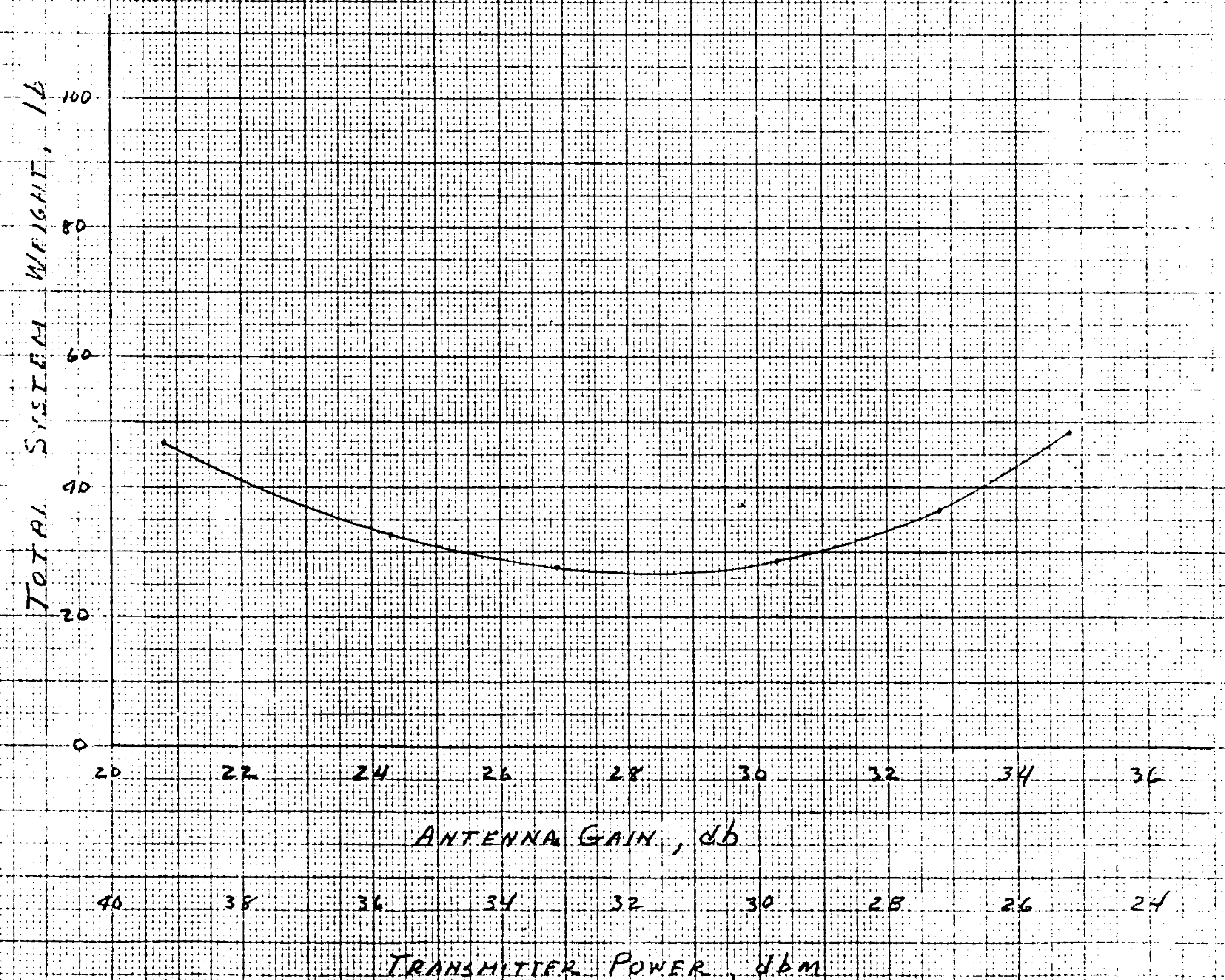
~~Miss Uncertainty for Different Acquisition Times and Effect of Acquisition Delay on Miss~~

Miss Uncertainty Versus Delay.

BILD (FIG.) 3

TOTAL SYSTEM WEIGHT VS ANTENNA GAIN FOR

1. GAIN-POWER PRODUCT = 60 dbm
2. 2300 mc
3. ANT WEIGHT = 0.5 lb/ft^2



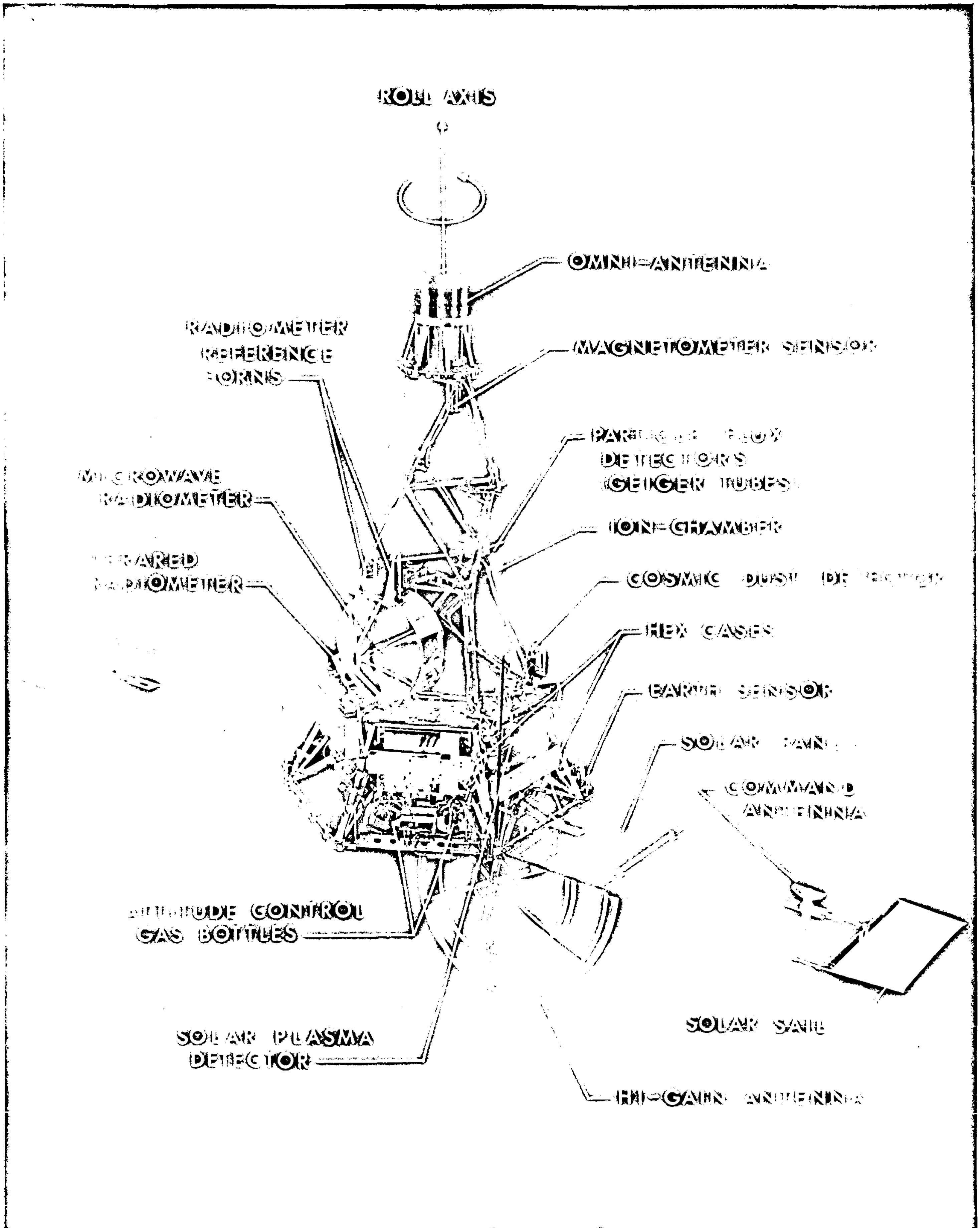


BILD (716.) 4 MARINER II SPACECRAFT

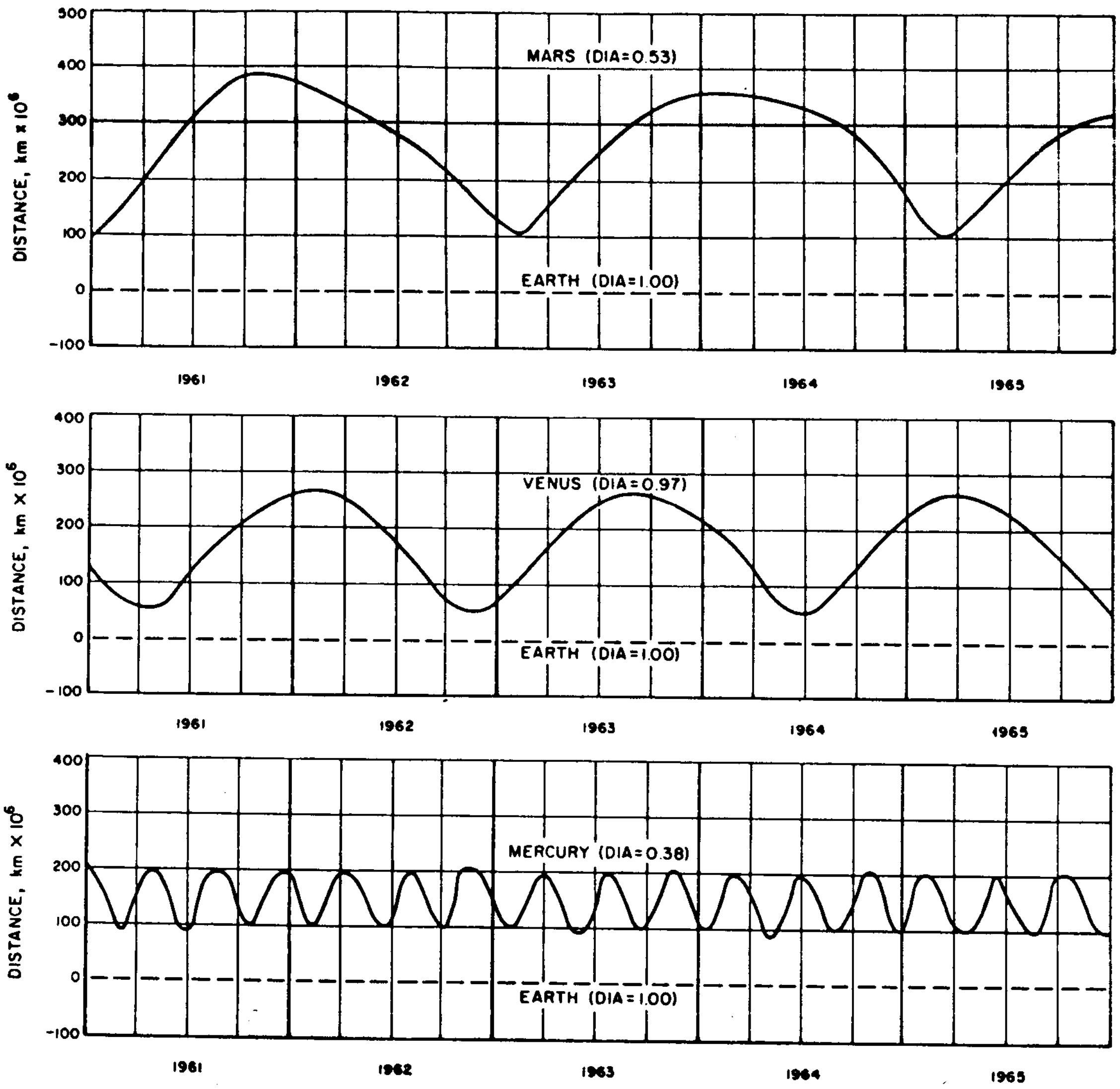


Bild (Fig) 5

Periodic Availability of the Planets Mars, Venus, and Mercury

Bild (Fig.) 6

The system is for the most part based on proven techniques and requires a minimum of new developments.

Bild (Fig.) 7

The system mechanizations are well understood, implying that the mechanizations can be analysed to the accuracy necessary to assure confidence in meeting the performance requirements.

Bild (Fig.) 8

New developments will have sufficient support in manpower and money and that there is a well established backup technique available.

MARINER 2 TELECOMMUNICATIONS SYSTEM

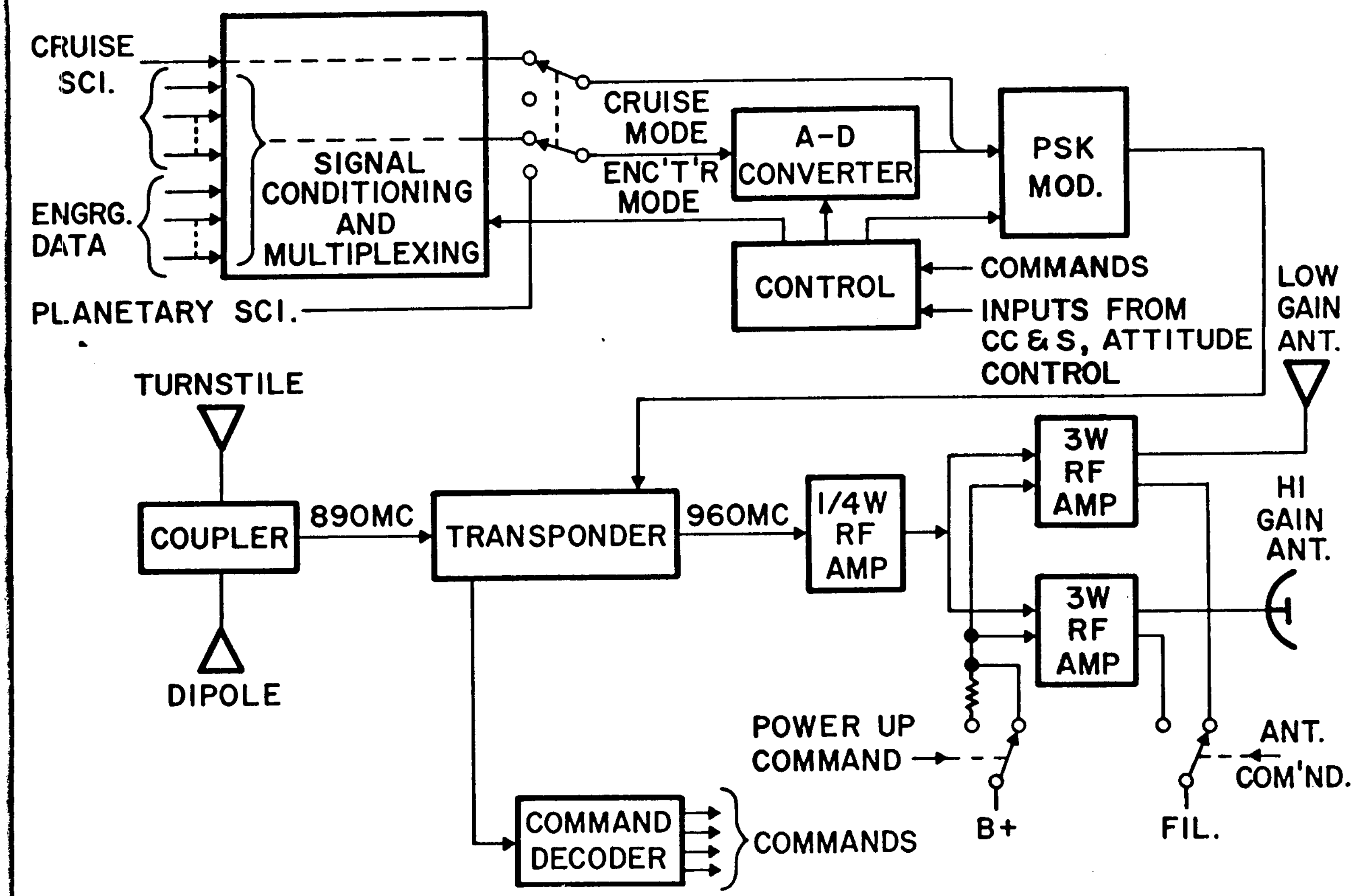


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Bild (Fig 9

Table 1

Telemetry Signal Classifications by Form

1. Analog
2. Digital
3. Event Pulse

Table II

Telemetry Signal Classification by

Measurement Requirements

1. Frequency response or sampling rate
2. Accuracy
3. Resolution
4. Cross correlation between measurements
5. Allowable delay

Table III

Telemetry Signal Classification by

Subsystem Source

1. Attitude Control
2. Temperature Control
3. Power
4. Propulsion
5. Telecommunication
6. Structure
7. Timing
8. Computing
9. Experimental instruments

Table IV

Telemetry Signal Classification by

Time of Source Activity

1. Continuous
2. Cruise phases
3. Maneuvers
4. Planetary encounter
5. Post encounter

Table V

Typical Mariner Command List

1. Discrete Commands

   a. Roll position override

   b. Clockwise hinge position override

   c. Counter-clockwise hinge position override

   d. Transmit via low gain antenna

   e. Transmit via high gain antenna

   f. Initiate midcourse maneuver

   g. Command encounter telemetry mode

   h. Command cruise telemetry mode

   i. Command sun acquisition

   j. Command cruise experiments off

   k. Command earth acquisition

2. Quantitative Commands

   a. Midcourse maneuver roll turn duration and polarity

   b. Midcourse maneuver pitch turn duration and polarity

   c. Midcourse maneuver velocity increment.

Table VI

Antenna Design Considerations

1. Specific operational requirements

2. Required angular coverage and gain

3. Required polarization characteristics

4. ~~Physical~~ Spacecraft structural configuration

5. Available antenna locations on the spacecraft.

TRACKING REQUIREMENTS

1. ANGULAR POSITION
   - a. LOCAL APPARENT HOUR ANGLE
   - b. LOCAL APPARENT DECLINATION
   - c. ACCURACY .... 0.01 TO 0.02 deg.
   - d. RESOLUTION .... 0.002 deg.

2. DOPPLER FREQUENCY SHIFT (RADIAL VELOCITY)
   - a. ACCURACY .... 0.2 m/sec.
   - b. RESOLUTION .... ± 1 cps AT 960 mc.
± 0.016 m/sec

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Table VIII

TELEMETRY DAT~~A~~ REQUIREMENTS

1. SPACECRAFT PERFORMANCE EVALUATION
   - a. SAMPLED ANALOG MEASUREMENTS 48
   - b. DIGITAL MEASUREMENTS 1
   - c. EVENT REGISTERS 4
2. SCIENTIFIC EXPERIMENT
   - a. SAMPLED ANALOG MEASUREMENTS 12
   - b. DIGITAL MEASUREMENTS 7

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Table ~~VIII~~ IX

TELEMETRY TRANSMISSION REQUIREMENTS

1. MODULATION TYPE
   - a. BINARY PHASE SHIFT KEYING
   - b. PSEUDORANDOM SYNC CODE
2. WORD LENGTH
   - a. PERFORMANCE DATA .... 7 bits
   - b. SCIENTIFIC DATA .... VARIABLE
3. TRANSMISSION RATES .... 8.33 & 33.3 bps
4. MAXIMUM BIT ERROR PROBABILITY .... 1.4×10^{-3}

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Fig ~~IX~~ X

COMMAND REQUIREMENTS

1. NUMBER OF COMMANDS
   - a. DISCREET 12
   - b. QUANTITATIVE 3
2. MODULATION TYPE
   - a. BINARY PHASE SHIFT KEYING
   - b. PSEUDORANDOM SYNC. CODE
3. WORD LENGTH .... 26 bits
4. RESOLUTION .... 18 bits
5. TRANSMISSION RATE .... 1 bps
6. MAXIMUM BIT ERROR PROBABILITY .... 1.0×10^{-5}

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Table XI

TABLE XII

TELECOMMUNICATION DESIGN CONTROL TABLE

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PROJECT: MARINER
CHANNEL: SPACECRAFT TO EARTH
MODE: HIGH GAIN, TRACKING, DIPLEXED, MASER

NO.	PARAMETER	VALUE	TOLERANCE	SOURCE
1	Total Transmitter Power (10 Watts)	+40.0 dbm	± 1.0 db	H.D.
2	Transmitting Circuit Loss	-1.5 db	± 0.4 db	PC, HD
3	Transmitting Antenna Gain	+23.5 db	+0.3, -0.5 db	SB
4	Transmitting Antenna Pointing Loss	-1.1 db	± 1.0 db	IK
5	Space Loss	-267.5 db	—	
	@ 2295 MC, R = 2.47×10^8 KM			
6	Polarization Loss	(INCLUDED IN ITEM 4)		
7	Receiving Antenna Gain	+53.0 db	+1.0, -0.5 db	J.R.H.
8	Receiving Antenna Pointing Loss	—	—	—
9	Receiving Circuit Loss	-0.2 db	± 0.1	JRH
10	Net Circuit Loss	-193.8 ~~[illegible]~~ db	+2.8, -2.5 db	
11	Total Received Power	-153.8 dbm	+3.8, -3.5 db	
12	Receiver Noise Spectral Density (N/B)	-181.2 dbm/cps	+0.7, -0.9 db	IK, JRH
	T System = 55 ± 10 °K			
13	Carrier Modulation Loss	-4.1 db	+0.7, -0.8 db	IK
14	Received Carrier Power	-157.9 dbm	+~~3.5~~ 4.5, -4.4 db	
15	Carrier APC Noise BW ($2B_{LO}$ = 12.0 cps)	+10.8 db·cps	+0.0, -0.5 db	JRH
	CARRIER PERFORMANCE FOR TELEMETRY ~~TRACKING (one-way)~~			
16	Threshold SNR in $2B_{LO}$	+6.0 db	—	BDM
17	Threshold Carrier Power	-164.4 dbm	+0.7, -1.4 db	
18	Performance Margin	+6.5 db	+5.9, -5.1 db	
	CARRIER PERFORMANCE-TRACKING (two-way)			
19	Threshold SNR in $2B_{LO}$			
20	Threshold Carrier Power			
	Performance Margin			

BILD (FIG) 10

MARINER [redacted] PERFORMANCE MARGIN VS TIME

TYPICAL TYPE 1 TRAJECTORY

SPACECRAFT-TO-EARTH CHANNEL CARRIER FOR 8 1/3 BPS
TELEMETRY TO DSS TRACKING DIPLEXED MASER